



ARI 22336.19 8H

Grant DAAG29-85-K-0026

NONLINEAR SURFACE POLARITONS

G. I. StegemanOptical Sciences CenterUniversity of ArizonaTucson, Arizona 85721

Approved for public release; distribution unlimited.

15 December 1987

Final Report for Period 15 November 1984 - 14 November 1987

Prepared for
ARMY RESEARCH OFFICE
Research Triangle Park, N. C.



18. REPORT SECURITY CLASSIFICATION Unclassified 28. DECLASSIFICATION AUTHORITY 28. DECLASSIFICATION TOWNGRADING SCHEDULE 29. PERFORMING ORGANIZATION REPORT NUMBER(S) 29. NAME OF PERFORMING ORGANIZATION REPORT NUMBER(S) 20. NAME OF PERFORMING ORGANIZATION REPORT NUMBER(S) 21. NAME OF PERFORMING ORGANIZATION NUMBER OF NUMBER(S) 22. NAME OF PUNDING/SPONSORING ORGANIZATION ONERS 23. NAME OF PUNDING/SPONSORING ORGANIZATION ONERS 24. NAME OF PUNDING/SPONSORING ORGANIZATION ONERS 25. NAME OF PUNDING/SPONSORING ORGANIZATION ONERS 26. ADDRESS (CIP, State, and ZIP Code) 26. ADDRESS (CIP, State, and ZIP Code) 27. NAME OF PUNDING/SPONSORING ORGANIZATION ORGANIZAT	REPORT	DOCUMENTATIO	N PAGE			Form Approved OMS No. 0704-018		
28. SCURITY CLASSIFICATION AUTHORITY 28. DECLASSIFICATION / DOWNGRADING SCHEDULE 4. PERFORMING ORGANIZATION REPORT NUMBER(S) 5. MONITORING ORGANIZATION REPORT NUMBER(S) 5. MONITORING ORGANIZATION REPORT NUMBER(S) 6. ADDRESS (City, Stete, and ZIP Code) University of Artzona Tucson, Az 35721 29. NAME OF PENDING / SPONSORING ONGANIZATION ATTER RESEARCH Office 80. DOPICE SYMBOL (If applicable) 70. ADDRESS (City, State, and ZIP Code) University of Funding / Sponsoring ONGANIZATION ATTER RESEARCH Office 80. ADDRESS (City, Stete, and ZIP Code) P.O. BOX 12211 80. NAME OF FUNDING / SPONSORING ONGANIZATION (If applicable) 81. DOPICE SYMBOL (If applicable) 82. ADDRESS (City, State, and ZIP Code) P.O. BOX 12211 83. NAME OF FUNDING / SPONSORING ONGANIZATION (If applicable) 84. DORESS (City, State, and ZIP Code) P.O. BOX 12211 19. FROM 1271 10. SOURCE OF FUNDING NUMBERS PROGRAD FINAL FROM 1271 10. SOURCE OF FUNDING NUMBERS PROGRAD FROM 1271 10. SOURCE OF FUNDING NUMBERS PROGRAD FROM 1271 10. SOURCE OF FUNDING NUMBERS PROGRAD FROM 1271/84, TOX 11/30/87 10. DATE OF REPORT (Year, Month, Day) 11. FACE COUNT PILL 11. COSATI CODES PROM 1271/84, TOX 11/30/87 11. SUPPLEMENTARY NOTATION 11. COSATI CODES PROGRAD PROGRA	1a. REPORT SECURITY CLASSIFICATION	16. RESTRICTIVE	MARKINGS					
A. PERFORMING ORGANIZATION REPORT NUMBER(S) S. MONITCHING ORGANIZATION REPORT NUMBER(S)								
ARO 22336.14-PH 4a. NAME OF PERFORMING ORGANIZATION Optical Sciences Center (ff applicable) CADORESS (Chy, State, and ZIP Code) University of Arizona Tucson, AZ 85721 Ba. NAME OF FUNDING /SPONSORING ORGANIZATION ORGANIZATI	2b. DECLASSIFICATION/DOWNGRADING SCHE	DULE						
ARO 22336.14-PH 4a. NAME OF PERFORMING ORGANIZATION Optical Sciences Center (ff applicable) CADORESS (Chy, State, and ZIP Code) University of Arizona Tucson, AZ 85721 Ba. NAME OF FUNDING /SPONSORING ORGANIZATION ORGANIZATI	4. PERFORMING ORGANIZATION REPORT NUM	IBER(S)	5. MONITORING	ORGANIZATIO	N REPORT NU	MBER(S)		
Sa. NAME OF PERFORMING ORGANIZATION Optical Sciences Center (**Pappikabba*) Optical Sciences Center (**Pappikabba*) Optical Sciences Center (**Pappikabba*) To. ADORESS (City, State, and ZIP Code) University of Arizona Tucson, AZ 85721 Sa. NAME OF FUNDING/SPONSORING ORGANIZATION Army Research Office RadoRESS (City, State, and ZIP Code) P.O. Box 12211 Research Triangle Park, NC 27709–2211 11. TITLE (**Include Security Classification*) Nonlinear Surface Polaritons — Unclassified 11. TITLE (**Include Security Classification*) Nonlinear Surface Polaritons — Unclassified 11. Supplementary NOTATION 11. Supplementary NOTATION 11. Supplementary NOTATION 11. Supplementary NOTATION 11. Analytical and numerical (the Beam Propagation Method) technique were used to analyze a variety of nonlinear optics planed and optical signal processing were identified. New nonlinear guided-wave phenomena have been predicted, of which many are of interest populations. The highlights are: (1) The generation of Solines predicted for nonlinear guided waves were found. Analytical land countering the second propagation in the optically induced index change. (2) East propagation for the first time. Furthermore, non-stationary nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guided waves obtained for the first time. Furthermore, non-stationary nonlinear guid						- 		
Sc. ADDRESS (City, State, and ZIP Code) University of Arizona Tucson, AZ 85721 Ba. NAME OF FUNDING/SPONSORING ORGANIZATION Army Research Office Bc. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211 PROSESS (City, State, and ZIP Code) P. O. Box 12211 PROSESS (City, State, an	68. NAME OF PERFORMING ORGANIZATION		7a. NAME OF M	ONITORING OR	GANIZATION			
University of Arizona Tucson, AZ 85721 Ba. NAME OF FUNDING/SPONSORING ORGANIZATION ATTRY Research Office Bc. ADDRESS (City, State, and ZIP Code) P.O. Box 12211 Research Triangle Park, NC 27709-2211 11. HTLE (Include Security Classification) Nonlinear Surface Polaritons - Unclassified 12. PERSONAL AUTHOR(S) G. I. Stegeman 13a. Type OF REPORT 13b. TIME COVERED FROM 12/1/84 Tol 11/30/87 87/12/15 11 15. SUBPLEMENTARY NOTATION 17. COSATI CODES 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) 19. ABSTRACT Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of necessary included waves premomen and device applications. The highlights are: (1) The analytical solutions for highly nonlinear guided waves of the included severation of solitons predicted for nonlinear waveguided waves for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, and optical logic via the exchange of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and index saturation in investigated. (3) Analytical and numerical solutions for nonlinear TM-polarized guided waves obtained for the first time. Furthermore, and optical logic via the exchange of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and inde	Optical Sciences Center	(Іт аррікасів)	ONRRR					
Bandolier Hall West Albutuerque NN 87131 Bandolier Mall West Albutuerque NN 87131 Bandolier Mall West Albutuerque NN 87131 Bandolier Mall West Albutuerque NN 87131 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAG29-85-K-0026 Bandolier Mall West Albutuerque NN 87131 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAG29-85-K-0026 Bandolier Mall West Albutuerque NN 87131 PROCUREMENT IDENTIFICATION NUMBER DAG29-85-K-0026 Bandolier Mall West Albutuerque NN 87131 PROCUREMENT IDENTIFICATION NUMBER DAG29-85-K-0026 DAG29-85-K-0026 DAG29-85-K-0026 DAG29-85-K-0026 TASK PROFECT TASK WORK UN LEMENT NO. IT. Steyeman 13. TYPE OF REPORT Final Task WORK UN LEMENT NO. 13. TYPE OF REPORT Final Task WORK UN LEMENT NO. 13. TYPE OF REPORT Final Task WORK UN LEMENT NO. 13. TASK WORK UN LEMENT NO. 14. DATE OF REPORT (Year, Month, Day) Task Bandolier Mall West Albutuerque NN 87131 TASK WORK UN LEMENT NO. 15. SOURCE OF FUNDING NUMBERS PROJECT TASK WORK UN LEMENT NO. 16. SUPPLEMENTARY NOTATION 17. COSATI CODES FIELD GROUP SUB-GROUP Nonlinear optics, nonlinear integrated optics, soliton emission and capture, optical limiters, waveguide bista 11ty, highly nonlinear guided waves 19. ABSTRACT Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of nonlinear optics phenomena at surfaces and in thin-film waveguides. A number of new device possibilities for allepotical signal processing were identified. New nonlinear guided-wave phenomena highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibit saturation in the optically induced index change. 20. Beam propagation techniques used to find the stability of nonlinear guided waves of non-ideal excitation conditions. waveguide absorption, and index saturation investigated. 4. Analytical and numerical solutions for nonlinear for the first time. 5. The generation of soliton	• •							
Albuquerque, MM 87131 Albuquerque, MM 87131 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAG29-85-K-0026 8c. ADDRESS (City, State, and ZIP Code) P.O. Box 12211 Research Triangle Park, NC 27709-2211 10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. NO. NO. NO. NO. NO. ACCESSION 11. ITILE (Include Security Classification) Nonlinear Surface Polaritons — Unclassified 12. PERSONAL AUTHORS) G. I. Stegeman 13a. TYPE OF REPORT 13b. Time COVERED FIND FIELD GROUP SUB-GROUP Nonlinear optics, nonlinear integrated optics, soliton emission and capture, optical limiters, waveguide bista lity, highly nonlinear guided waves 19. ABSTRACT Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of anolinear optics phenomena at surfaces and in thin-film waveguides. A number of new device possibilities for allsopical signal processing were identified. New nonlinear guided-wave phenomena have been predicted, of which many are of interest for potential experimental and device applications. The highlights are: (1) The analytical solutions for highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibit saturation in the optically induced index change. (2) Beam propagation techniques used to find the stability of nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. (3) The generation of solitons predicted for nonlinear guided waves obtained for the first time. (4) Analytical and numerical solutions for nonlinear gu			•					
ATMY Research Office BLADDRESS (CTP, State, and ZIP Code) P.O. Box 12211 Research Triangle Park, NC 27709-2211 10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. NO. NO. ACCESSION RELEMENT NO. NO. NO. ACCESSION 11. TITLE (Include Security Classification) Nonlinear Surface Polaritons - Unclassified 12. PERSONAL AUTHOR(S) G. I. Stegeman 13a. TYPE OF REPORT FROM 12/1/84 rot 11/30/87 87/12/15 11. SUPPLEMENTARY NOTATION 12. COSATI CODES 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Nonlinear optics, nonlinear integrated optics, soliton emission and capture, optical limiters, waveguide bista 1ity, highly nonlinear guided waves 19. ABSTRACT Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of nonlinear guided waves penomena have been predicted, of which many are of interest for potential experimental and device applications. The highlights are: (1) The analytical solutions for highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibit saturation in the optically induced index change. (2) Beam propagation techniques used to find the stability of nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided for saturation investigated. (3) The generation of solitons predicted for nonlinear waveguides excited at high powers. Applications to optical limiters and optical logic via the exchange of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and index saturation investigated. (4) Analytical and numerical solutions for interest fully explained for the first time. (5) The response of nonlinear directional couplers to very high excitation calculated, res. Iting in unexpected steady-state conditions. 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT DIC USERS 21. ABSTRACT SECURITY CLASSIFICATION 222. NAME OF RESPONSIBLE INDIVIDUAL 223. NAME OF RESPONSIBLE INDIVIDUAL			Albuquera	ie. NM 871	.31			
Army Research Office 8. ADDRESS (City, State, and ZiP Code) P.O. Box 12211 Research Triangle Park, NC 27709-2211 10. SOURCE OF FUNDING NUMBERS PROGRAM REMENT NO. 11. STILE (Include Security Classification) Nonlinear Surface Polaritons - Unclassified 12. PERSONAL AUTHOR(S) G. I. Stegeman 13. TYPE OF REPORT Final FROM 12/1/84 TOE 11/30/87 16. SUPPLEMENTARY NOTATION 17. COSATI CODES FIELD GROUP SUB-GROUP Nonlinear optics, nonlinear integrated optics, soliton emission and capture, optical limiters, waveguide bista 1ity, highly nonlinear guided waves 19. ABSTRACT Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of nonlinear optics phenomena a surfaces and in thin-film waveguides. A number of new device possibilities for allisoptical signal processing were identified. New nonlinear guided-wave phenomena have been predicted, of which many are of interest for potential experimental and device applications. The highlights are: (1) The analytical solutions for highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibits saturation in the optically induced index change. (2) Beam propagation techniques used to find the stability of nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. (3) The generation of solitons predicted for nonlinear waveguides excited at high powers. Applications to optical limiters and optical logic via the exchange of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and index saturation investigated. (4) Analytical and numerical solutions for nonlinear rume guided waves obtained for the first time. (5) The feasibility of light-by-light modulation using nonlinear guided waves obtained for the first time. (6) The response of nonlinear directional couplers to very high excitation calculated, res. Iting in unexpected steady-state conditions. 21. ASSTRACT SECURITY CLASSIFICATIO			9. PROCUREMEN	TINSTRUMENT	IDENTIFICATI	ON NUMBER		
PROGRAM ELEMENT NO. PROJECT TASK NORK UN ACCESSION 11. ITILE (Include Security Classification) Nonlinear Surface Polaritons — Unclassified 12. PERSONAL AUTHOR(S) G. I. Stegeman 13a. TYPE OF REPORT [13b. TIME COVERED FROM 12/1/84 TOR 11/30/87] FIGUS GROUP SUB-GROUP IT. COSATI CODES 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Nonlinear optics, nonlinear integrated optics, soliton emission and capture, optical limiters, waveguide bista 1tty, highly nonlinear guided waves 19. ABSTRACI Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of nonlinear optics phenomena at surfaces and in thin-film waveguides. A number of new device possibilities for all-loptical signal processing were identified. New nonlinear guided-wave phenomena have been predicted, of which many are of interest for potential experimental and device applications. The highlights are: (1) The analytical solutions for highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibit saturation in the optically induced index change. (2) Beam propagation techniques used to find the stability of nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. (3) The genomenation of the change of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and index saturation investigated. (4) Analytical and numerical solutions for nonlinear tampelarized guided waves obtained for the first time. (5) The feasibility of light-by-light modulation using nonlinear guided waves obtained for the first time. (6) The origin of bistability in nonlinear prism couplers fully experiment for the first time. (7) The response of nonlinear directional couplers to very high excitation calculated, res. Iting in unexpected steady-state conditions.	Army Research Office							
Research Triangle Park, NC 27709-2211 Research Triangle Park (Continue on reverse if necessary and identify by block number on the County of Nonlinear guided waves and inten	<u> </u>					Time and the second		
11. TITLE (Include Security Classification) Nonlinear Surface Polaritons - Unclassified 12. PERSONAL AUTHOR(S) G. I. Stegeman 13a. TYPE OF REPORT 13b. TIME COVERED 14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT Final FROM.12/1/84 TOL.11/30/87 87/12/15 11 16. SUPPLEMENTARY NOTATION 17. COSATI CODES 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Nonlinear optics, nonlinear integrated optics, soliton emission and capture, optical limiters, waveguide bista litry, highly nonlinear guided waves 19. ABSTRACT Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of nonlinear optics phenomena at surfaces and in thin-film waveguides. A number of new device possibilities for alleoptical signal processing were identified. New nonlinear guided-wave phenomena have been predicted, of which many are of interest for potential experimental and device applications. The highlights are: (1) The analytical solutions for highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibit saturation in the optically induced index change. (2) Beam propagation techniques used to find the stability of nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. (3) The generation of solitons predicted for nonlinear waveguides excited at high powers. Applications to optical limiters and optical logic via the exchange of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and index saturation investigated. (4) Analytical and numerical solutions for nonlinear TM-polarized guided waves obtained for the first time. (5) The response of nonlinear directional couplers to very high excitation calculated, res. Iting in unexpected steady-state conditions. (6) The origin of bistability in nonlinear prism couplers fully explained for the first time. (7) The response of nonlinear directional		7709-2211				ACCESSION		
Nonlinear optics, nonlinear integrated optics, soliton emission and capture, optical limiters, waveguide bista lity, highly nonlinear guided waves 19. ABSTRACT Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of nonlinear optics phenomena at surfaces and in thin-film waveguides. A number of new device possibilities for all-potical signal processing were identified. New nonlinear guided-wave phenomena have been predicted, of which many are of interest for potential experimental and device applications. The highlights are: (1) The analytical solutions for highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibit saturation in the optically induced index change. (2) Beam propagation techniques used to find the stability of nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. (3) The generation of solitons predicted for nonlinear waveguides excited at high powers. Applications to optical limiters and optical logic via the exchange of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and index saturation investigated. (4) Analytical and numerical solutions for nonlinear TM-polarized guided waves obtained for the first time. (5) The feasibility of light-by-light modulation using nonlinear guided waves obtained for the first time. (6) The origin of bistability in nonlinear prism couplers fully explained for the first time. (7) The response of nonlinear directional couplers to very high excitation calculated, res. Iting in unexpected steady-state conditions. 21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED/UNLIMITED SAME AS RPT. DIIC USERS 222. NAME OF RESPONSIBLE INDIVIDUAL FLOOR SAME AS RPT. DIIC USERS	13a. TYPE OF REPORT 13b. TIME FROM 12		14. DATE OF REPO 87/12/15	DRT (Year, Mo n	nth, Day) 15.			
19. ABSTRACT Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of nonlinear optics phenomena at surfaces and in thin+film waveguides. A number of new device possibilities for all+optical signal processing were identified. New nonlinear guided-wave phenomena have been predicted, of which many are of interest for potential experimental and device applications. The highlights are: (1) The analytical solutions for highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibit saturation in the optically induced index change. (2) Beam propagation techniques used to find the stability of nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. (3) The generation of solitons predicted for nonlinear waveguides excited at high powers. Applications to optical limiters and optical logic via the exchange of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and index saturation investigated. (4) Analytical and numerical solutions for nonlinear TM-polarized guided waves obtained for the first time. (5) The feasibility of light-by-light modulation using nonlinear guided waves of both polarizations predicted. (6) The origin of bistability in nonlinear prism couplers fully explained for the first time. (7) The response of nonlinear directional couplers to very high excitation calculated, res.!ting in unexpected steady-state conditions. 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNILIMITED SAME AS RPT. DITIC USERS 21. ABSTRACT SECURITY CLASSIFICATION 222. TELEPHONE (Include Area Code) 22c. OFFICE SYMBOL (602) 621-6996	13a. TYPE OF REPORT Final 16. SUPPLEMENTARY NOTATION	<u>2/1/84</u> то <u>в 11/30</u> /87	87/12/15			11		
Analytical and numerical (the Beam Propagation Method) techniques were used to analyze a variety of nonlinear optics phenomena at surfaces and in thin+film waveguides. A number of new device possibilities for all+optical signal processing were identified. New nonlinear guided-wave phenomena have been predicted, of which many are of interest for potential experimental and device applications. The highlights are: (1) The analytical solutions for highly nonlinear waves guided by single interfaces and thin films extended to realistic media which exhibit saturation in the optically induced index change. (2) Beam propagation techniques used to find the stability of nonlinear guided waves for the first time. Furthermore, non-stationary nonlinear guided waves were found, also for the first time. (3) The generation of solitons predicted for nonlinear waveguides excited at high powers. Applications to optical limiters and optical logic via the exchange of solitons identified. The effects of non-ideal excitation conditions, waveguide absorption, and index saturation investigated. (4) Analytical and numerical solutions for nonlinear TM-polarized guided waves obtained for the first time. (5) The feasibility of light-by-light modulation using nonlinear guided waves of both polarizations predicted. (6) The origin of bistability in nonlinear prism couplers fully explained for the first time. (7) The response of nonlinear directional couplers to very high excitation calculated, res. Iting in unexpected steady-state conditions. 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED SAME AS RPT. DITIC USERS 21. ABSTRACT SECURITY CLASSIFICATION 22b. TELEPHONE (Include Area Code) 22c. OFFICE SYMBOL (602) 621-6996	13a. TYPE OF REPORT Final 16. SUPPLEMENTARY NOTATION 17. COSATI CODES	2/1/84 TOL 11/30/87	87/12/15	se if necessary	and identify b	11 by block number)		
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED SAME AS RPT. DTIC USERS 21. ABSTRACT SECURITY CLASSIFICATION 22b. TELEPHONE (Include Area Code) 22c. OFFICE SYMBOL Floyd Lance (602) 621-6996	13a. TYPE OF REPORT Final 16. SUPPLEMENTARY NOTATION 17. COSATI CODES FIELD GROUP SUB-GROUP	18. SUBJECT TERMS Nonlinear op emission and lity, highly	Continue on revertics, nonline capture, optononlinear grounds	e if necessary ear integr tical limi	and identify to tated opti ters, wav	ll by block number) cs, soliton reguide bistal		
22a. NAMÉ OF RESPONSIBLE INDIVIDUAL Floyd Lance 22b. TELEPHONE (Include Area Code) (602) 621-6996 22c. OFFICE SYMBOL (602) 621-6996	13a. TYPE OF REPORT Final 16. SUPPLEMENTARY NOTATION 17. COSATI CODES FIELD GROUP SUB-GROUP 19. ABSTRACT Analytical and numerical nonlinear optics phenomena all-poptical signal processing with New nonlinear guided-with experimental and device apple (1) The analytical solutions realistic media which ex (2) Beam propagation techn Furthermore, non-stations (3) The generation of solitic optical limiters and optic conditions, waveguide ab (4) Analytical and numerica (5) The feasibility of light-be (6) The origin of bistability (7) The response of nonline	18. SUBJECT TERMS Nonlinear op emission and lity, highly I (the Beam Propagation aver phenomena have be lications. The highlight for highly nonlinear we hibit saturation in the charm of the color of	(Continue on revertics, nonlinear grant management of the continue on revertics, nonlinear grant management of the continue of	e if necessary ear integratical limit and a wave integrated wave interface in the state of the first of the state of the s	and identify be rated optileters, waves issed to analy of new device are of interest and thin find waves for first time. The igh powers of the polarization of the pol	by block number) cs, soliton reguide bistab rze a variety of e possibilities for rest for potential films extended to r the first time. Applications to n-ideal excitation the first time. ons predicted.		
	13a. TYPE OF REPORT Final 16. SUPPLEMENTARY NOTATION 17. COSATI CODES FIELD GROUP SUB-GROUP 19. ABSTRACT Analytical and numerical nonlinear optics phenomena alli-optical signal processing with New nonlinear guided-with experimental and device apple (1) The analytical solutions realistic media which experimental and device apple (2) Beam propagation techn Furthermore, non-stations (3) The generation of solitic optical limiters and optic conditions, waveguide at (4) Analytical and numerical (5) The feasibility of light-be (6) The origin of bistability (7) The response of nonline steady-state conditions. 20. DISTRIBUTION/AVAILABILITY OF ABSTRACE	18. SUBJECT TERMS Nonlinear op emission and lity, highly I (the Beam Propagation at surfaces and in thin- were identified. ave phenomena have be lications. The highlight for highly nonlinear w hibit saturation in the c iques used to find the ary nonlinear guided was one predicted for nonlinear proposition, and index satu I solutions for nonlinear oy-light modulation using in nonlinear prism couplers T	Continue on revertics, nonline capture, opinonlinear gun Method) technifilm waveguides. The predicted, of sare: aves guided by suptically induced in estability of no aves were found, the average of solitons identication investigate TM-polarized gun onlinear guideo plers fully explain to very high exceptions.	which many index change. Index change. Index change. Index change. Index change. Index change. Index change also for the fexcited at hintified. The d. Index change index change index change also for the first change. Index change in the chang	and identify be rated optiluters, waves issed to analy of new device are of interes and thin fed waves for first time. If it is in the polarization of the polarizatio	by block number) cs, soliton reguide bistab rze a variety of e possibilities for rest for potential films extended to r the first time. Applications to n-ideal excitation the first time. ons predicted.		
	13a. TYPE OF REPORT Final 16. SUPPLEMENTARY NOTATION 17. COSATI CODES FIELD GROUP SUB-GROUP 19. ABSTRACT Analytical and numerical nonlinear optics phenomena alli-optical signal processing with New nonlinear guided-with experimental and device apple (1) The analytical solutions realistic media which experimental and device apple (2) Beam propagation technological limiters and optical limiters and optic conditions, waveguide at (4) Analytical and numerical (5) The feasibility of light-be (6) The origin of bistability (7) The response of nonline steady-state conditions. 20. DISTRIBUTION/AVAILABILITY OF ABSTRACE UNCLASSIFIED/UNILIMITED SAME AS 2228. NAME OF RESPONSIBLE INDIVIDUAL	18. SUBJECT TERMS Nonlinear op emission and lity, highly I (the Beam Propagation at surfaces and in thin- were identified. ave phenomena have be lications. The highlight for highly nonlinear w hibit saturation in the c iques used to find the ary nonlinear guided was one predicted for nonlinear proposition, and index satu I solutions for nonlinear oy-light modulation using in nonlinear prism couplers T	Continue on revertics, nonline capture, opinonlinear guine method technifilm waveguides. The polarized guine investigate TM-polarized guiners fully explaint to very high exceptions.	which many ingle interface also for the fixed waves of being also for the fixed waves of	and identify be rated optiluters, waves used to analy of new device are of interest and thin fed waves for first time. If it is interest time in the polarization of t	by block number) cs, soliton reguide bistab reguide bistab reguide bistab reguide bistab rest for potential films extended to rethe first time. Applications to n-ideal excitation the first time. ons predicted. ag in unexpected		

TABLE OF CONTENTS

INTRODUCTION	1
REVIEW OF ACCOMPLISHMENTS	
Background	I
Results	2
Conclusion	4
PUBLICATIONS WITH GRANT SUPPORT	4

	Accession For	
	NTIS GRANI DTIC TAB Unannounced Justification	
Part of	[
(const	Distribution/	
	Availability Codes	
	Avail and/or Dist Special	

INTRODUCTION

In the last few decades, nonlinear optics has taken a central role in many applications based on four-wave mixing and an intensity-dependent refractive index. Two of the most intriguing questions posed in the last few years are: 1) what role, if any, solitons will play in optics, and 2) whether sub-picosecond all-optical signal processing based on guided waves will be possible. Solutions to the nonlinear wave equation for media containing Kerr-law nonlinearities were known for a number of years prior to the start of this program. However, only recently, with this research program playing a leading role, have numerical investigations revealed the full richness of the phenomena involved. Power-dependent waves guided by the interface between two media (at least one of which has a self-focusing nonlinearity; i.e., index increases with power) were studied initially. It was soon realized however, that a thin film bounded by media of lower index (at low guided-wave powers) is the optimum geometry, since it also supports guided waves at low powers, commonly known as integrated-optics waveguides. Waveguides are ideal for efficient nonlinear interactions because they confine light to beam cross-sections on the order of the wavelength of light. Consequently, much of our work has concentrated on thin-film waveguides.

Three years ago this program to investigate nonlinear surface polariton phenomena was begun, in collaboration with A. A. Maradudin and R. F. Wallis at the University of California at Irvine. In the last eighteen months, most specifically with the arrival of E. M. Wright (recently promoted to Research Assistant Professor), an independent theory program has been developed at the University of Arizona. Simultaneously, both the fundamental and device-related aspects of nonlinear guidedwave interactions were under experimental investigation.

REVIEW OF ACCOMPLISHMENTS

Background

The theoretical program has led to a number of significant advances in the understanding of nonlinear guided-wave phenomena and has identified a number of potential applications to all-optical devices. The results have been reported in a series of publications, ¹⁻³¹ and led to a number of invited papers ³²⁻⁵² concerning both experiment and theory.

The geometry examined most frequently consists of a thin film (of refractive index n_f) bounded by a nonlinear cladding ($n = n_c + n_{2c}S$) and/or a nonlinear substrate ($n = n_s + n_{2s}S$), where S is the local intensity. For TE waves polarized in the y direction, Maxwell's equations lead to the following mixed linear-nonlinear Schrodinger equation governing the evolution of the complex electric field:

$$\frac{\partial^2 E}{\partial x^2} + 2i\beta k \frac{\partial E}{\partial z} - k^2 [\beta^2 - n^2(x,S)] E = 0.$$

Here z and x are the propagation and transverse coordinates, and β is an appropriate background effective index. This equation admits nonlinear guided-wave solutions of the form

$$E(x,z) = E_g(x,P_{gw})e^{ik\beta[P_{gw}] z},$$

where, in general, both the guided-wave effective index and the field profile depend on the guided-wave power, P_{gw} . It is usually the variation in β and $E_g(x)$ with guided-wave power which leads to unusual and potentially useful properties of the guided waves. This program has primarily used two approaches to solve these equations for a variety of multilayer geometries. Steady-state solutions are obtained when $\partial E/\partial z = 0$. Beam propagation methods are particularly valuable for investigating cases where $\partial E/\partial z \neq 0$.

Results

The following phenomena, based on steady-state solutions to the nonlinear wave equation, have been demonstrated theoretically. Ideal Kerr-law nonlinearities in the media bounding the film were assumed.

- (1) For self-focusing media and under well-defined conditions, there is a threshold power above which guiding occurs. This leads to an all-optical lower threshold device. 1-5,15,16,20
- (2) For self-defocusing media, there is an upper limit to the power guided. This is essentially an optical limiter.^{1-5,15,16,20}

 The combination of these two effects could lead to an all-optical Schmitt trigger, a key component in any all-optical system.
- (3) Saturation effects have been included in the steady-state solutions and the effect on various nonlinear guided waves clarified. In particular, it was shown that a

value for the saturation index which is too small eliminates thresholding action for (1) and (2) above.^{6,7,12,13,15,16,20}

This result identifies a material limitation on the operation of all-optical devices.

In addition, numerical beam propagation methods (BPM) have been developed in collaboration with J. V. Moloney of Heriot-Watt University and the following results obtained.

- (4) Not all of the nonlinear guided-wave branches for self-focusing bounding media are stable. Unstable solutions emit spatial solitons into the bounding media as they evolve into stable solutions. 10,13,16,20
- (5) Nonstationary, stable solutions to the nonlinear wave equation in which the field distributions remain guided and oscillate with distance were discovered. 11,13,16,18-20
- (6) Stable waves can be excited by focusing appropriately tailored Gaussian beams onto the endface of a nonlinear waveguide. If the power is too high, the excess power leaves the film region by means of successive emission of solitons, thus limiting the power guided in the region of the film. 18-21,24
- (7) Absorption leads to interesting overshoot phenomena for soliton-like waves. In the limit of weak absorption, soliton propagation still occurs.²²
- (8) Until recently, all of the progress by this group and others in the field has been for TE-polarized waves. The TM case was generally believed to be intractable; however, analytical formulae for the TM dispersion curves have been obtained for the first time. Also, in collaboration with A. D. Boardman's group, purely numerical techniques were applied to the solution of the TM problem. 17,25,26
- (9) Solving the TM problem allowed consideration of weak-strong beam combinations for combination TE- and TM-polarized waves. It has been shown that 100% modulation of one beam by a weak modulation of the second beam is possible.^{27,28}
- (10) There is a long-standing controversy about whether bistability can be obtained when light is prism-coupled into a nonlinear waveguide. It was shown numerically that bistability can be obtained only with non-local nonlinearities, or with reflections at the prism end. Purely local nonlinearities lead only to switching.²⁹

This explains the observation of bistability for thermal nonlinearities in a number of experiments by this group and others.

(11) One of the potentially most versatile all-optical guided-wave devices is the nonlinear directional coupler. The steady-state response of this device has been solved. A number of totally unexpected steady-state power distributions between the two channels were found.³¹

Conclusion

In terms of applications, the above results identify which branches of the new solutions can actually be used to propagate guided-wave power. The common occurrence of spatial solitons in these nonlinear systems begs the question of whether new device concepts based on the exchange of solitons are possible. Research is continuing in this area.

PUBLICATIONS

- 1. C. T. Seaton, J. D. Valera, and G. I. Stegeman, "Integrated optics optical limiters," in Proceedings of AGARD Conference on Guided Waves in the Military Environment (AGARD, Paris, 1985).
- 2. C. T. Seaton, G. I. Stegeman, and H. G. Winful, "Nonlinear planar guided wave interactions and devices," in Proceedings of AGARD Conference on Guided Waves in the Military Environment (AGARD, Paris, 1985).
- 3. J. Ariyasu, C. T. Seaton, and G. I. Stegeman, "Power dependent attenuation of nonlinear waves guided by thin films," Appl. Phys. Lett. 47, 355 (1985).
- 4. G. I. Stegeman, C. T. Seaton, J. Ariyasu, R. F. Wallis, and A. A. Maradudin, "Nonlinear waves guided by a single interface," J. Appl. Phys. 58, 2453 (1985).
- J. Ariyasu, C. T. Seaton, G. I. Stegeman, A. A. Maradudin, and R. F. Wallis, "Nonlinear surface polaritons guided by metal surfaces," J. Appl. Phys. 58, 2460 (1985).
- 6. C. T. Seaton, J. Ariyasu, G. I. Stegeman, and T. P. Shen, "Nonlinear thin film guided waves in non-Kerr media," Appl. Phys. Lett. 47, 1254 (1985).

- 7. G. I. Stegeman, C. T. Seaton, J. Ariyasu, and T. P. Shen, "Nonlinear waves guided by the interface of a non-Kerr-like medium," Opt. Commun. 56, 365 (1986).
- 8. J. J. Burke, G. I. Stegeman, and T. Tamir, "Surface polariton-like waves guided by thin, lossy metal films," Phys. Rev. B 33, 5186 (1986).
- 9. J. Ariyasu, C. T. Seaton, G. I. Stegeman, and J. V. Moloney, "New theoretical developments in nonlinear guided waves: stability of TE₁ branches," IEEE J. Quant. Electron. QE-22, 984 (1986).
- J. V. Moloney, J. Ariyasu, C. T. Seaton, and G. I. Stegeman, "Stability of nonlinear stationary waves guided by a thin film bounded by nonlinear media," Appl. Phys. Lett. 48, 826 (1986).
- 11. J. V. Moloney, J. Ariyasu, C. T. Seaton, and G. I. Stegeman, "Numerical evidence for non-stationary nonlinear guided waves," Opt. Lett. 11, 315 (1986).
- G. I. Stegeman, E. M. Wright, C. T. Seaton, J. V. Moloney, T. P. Shen, A. A. Maradudin, and R. F. Wallis, "New theoretical developments in nonlinear guided waves: non Kerr-like media," IEEE J. Quant. Electron. QE-22, 977 (1986).

KOSOSOS, PROPORO SOPROON POLICIONO PROPINS

- G. I. Stegeman, J. Ariyasu, C. T. Seaton, and J. V. Moloney, "Nonlinear waves guided by non-Kerr like media," in Proceedings of 1986 Integrated and Guided Wave Optics Conference (Atlanta, 1986).
- 14. T. P. Shen, R. F. Wallis, A. A. Maradudin, and G. I. Stegeman, "Reflection and transmission of guided waves at end faces," JOSA B, in press.
- 15. G. I. Stegeman and C. T. Seaton, "Numerical and experimental studies of nonlinear EM guided waves," in Proceedings of Second International Conference on Surface Waves in Plasmas and Solids, S. Vukovic, ed. (World Scientific Publishers, Singapore, 1986).

- 16. G. I. Stegeman C. T. Seaton, A. Boardman, and P. Egan, "Nonlinear guided waves," in Proceedings of NATO Summer School on Surface Electromagnetic Excitations, R. F. Wallis and G. I. Stegeman, eds. (Springer-Verlag, Berlin, 1986); also in Proceedings of NATO Summer School on Nonlinear Optics: Materials and Devices (Springer-Verlag), in press.
- 17. D. Mihalache, G. I. Stegeman, C. T. Seaton, E. M. Wright, R. Zanoni, T. Twardowski, and A. D. Boardman, "Exact dispersion relations solutions for TM polarized guided waves at a nonlinear interface," Opt. Lett. 12, 178 (1987).
- 18. E. M. Wright, G. I. Stegeman, C. T. Seaton, and J. V. Moloney, "Gaussian beam excitation of TE₀ nonlinear guided waves," Appl. Phys. Lett. 49, 435 (1986).
- 19. E. M. Wright, G. I. Stegeman, C. T. Seaton, J. V. Moloney, and A. D. Boardman, "Multi-soliton emmission and optical limiting in a nonlinear waveguide," Phys. Rev. A 34, 4442 (1986).
- G. I. Stegeman and C. T. Seaton, "Nonlinear waves guided by multilayer media," in Proceedings of the International Symposium on Surface Waves in Solids and Layered Structures, Vol. III (Novosibirsk, USSR, 1986).

- 21. E. M. Wright, C. T. Seaton, G. I. Stegeman, and J. V. Moloney, "Multisoliton emmission in nonlinear waveguides," in Proceedings of the Twelfth European Conference on Optical Communication (Telefonica, Madrid, 1986).
- 22. M. Gubbels, E. M. Wright, G. I. Stegeman, C. T. Seaton, and J. V. Moloney, "Effects of absorption on TE₀ nonlinear guided waves," Opt. Commun. 61, 357 (1987).
- 23. N. Finlayson, C. T. Seaton, G. I. Stegeman, and Y. Silberberg, "Beam propagation study of nonlinear coupling between transverse electric modes of a slab waveguide," Appl. Phys. Lett. 22, 1562 (1987).
- 24. M. A. Gubbels, E. M. Wright, G. I. Stegeman, C. T. Seaton, and J. V. Moloney, "Numerical study of soliton emmission from a nonlinear waveguide," JOSA B 11, 1837 (1987).

- A. D. Boardman, A. A. Maradudin, G. I. Stegeman, T. Twardowski, and E. M. Wright, "Exact theory of nonlinear p-polarized optical waves," Phys. Rev. A, 35, 1159 (1987).
- A. D. Boardman, T. Twardowski, A. Shivarova, and G. I. Stegeman, "Surface-guided nonlinear TM waves in planar waveguides," IEEE Proceedings, 134, 152 (1987).
- 27. J. Shen, A. A. Maradudin, and G. I. Stegeman, "Low power, single-interface guided waves mediated by high power nonlinear guided waves: TE case," submitted to JOSA B.
- 28. J. Shen, G. I. Stegeman, and A. A. Maradudin, "Light by light modulation with nonlinear guided waves," Appl. Phys. Lett. in press.
- G. I. Stegeman, G. Assanto, R. Zanoni, C. T. Seaton, E. Garmire, A. A. Maradudin, R. Reinisch, and G. Vitrant, "Bistability and switching in nonlinear prism coupling," submitted to Appl. Phys. Lett.
- V. M. Agranovich, T.A. Leskova, A. A. Maradudin, T. P. Shen, G. I. Stegeman, and R. F. Wallis, "Diffraction of surface polaritons and guided wave polaritons," Progress in Surface Science, in press.
- 31. S. Y. Shin, E. M. Wright, and G. I. Stegeman, "Nonlinear TE waves of coupled waveguides bounded by nonlinear media," submitted to IEEE J. Lightwave Tech.
- 32. "Nonlinear Surface Polaritons." Ettore Majorana Summer School on Dynamical Phenomena at Surfaces, Interfaces, and Superlattices, Erice, Italy, 1984.
- 33. "Nonlinear Third Order Integrated Optics," European Conference on Integrated Optics (EICO'85), Berlin, 1985.
- 34. "Nonlinear Guided Wave Phenomena," (four lectures) Ettore Majorana Summer School on Surface Electromagnetic Excitations, and at Summer School on Nonlinear Optics, Erice, Italy, 1985.

- 35. "Nonlinear Waves Guided by Surfaces," Second International Conference on Surface Waves, Ohrid, Yugoslavia, 1985.
- 36. "Nonlinear Guided Wave Phenomena: Physics and Applications," Trends in Quantum Electronics '85, Bucharest, 1985.
- 37. "Intensity-Dependent Guided Wave Phenomena," Second International Conference on Optical Circuit Engineering, Cambridge, 1985.
- 38. "New Developments in Nonlinear Waveguide Theory," Tenth Workshop on Optical Waveguide Theory, Castel Gandolfo, Italy, 1985.
- 39. "Nonlinear Planar Guided Wave Interactions," AGARD (NATO) Meeting on Guided Optical Structures, Istanbul, 1985.
- 40. "Nonlinear Integrated Optics," Fifth International Conference on Integrated Optics and Optical Fibre Communications, Venice, 1985.
- 41. "Nonlinear Guided Wave Phenomena," Topical Conference on Optical Bistability, Tucson, 1985.
- 42. "Recent Developments in Nonlinear Guided Waves," Conference on Lasers and Electrooptics" (CLEO), San Francisco, 1986.
- 43. "Nonlinear Waves Guided by Multilayer Media," International Symposium on Surface Waves in Solids and Layered Structures," Novosibirsk, USSR, 1986.
- 44. "Third Order Nonlinear Guided Wave Optics," SPIE Conference on Molecular and Polymeric Optoelectronic Materials: Fundamentals and Applications, San Diego, 1986.
- 45. "Soliton Effects in Nonlinear Waveguides," Eleventh Workshop on Optical Waveguide Theory, Madrid, 1986.
- 46. "Nonlinear Integrated Optics: Materials and Devices," Basic Science, Glass and Electronics Joint Meeting of the American Ceramic Society, New Orleans, 1986.

- 47. "The State of the Art of, and Future Research Needs in Integrated Optics Structures," NSF Workshop on The Molecular Engineering of Ultrathin Polymeric Films, Davis, California, 1987.
- 48. "Experiments in and Device Applications of Nonlinear Waveguides," Workshop on State of the Art Developments in Nonlinear Optics, Tucson, 1987.
- 49. "Linear and Nonlinear Optical Phenomena at Surfaces," USA-USSR Binational Symposium on Laser Optics of Condensed Matter, Leningrad, 1987.
- 50. "Nonlinear Optics in Waveguides," Annual Meeting of Canadian Association of Physicists, Toronto, 1987.
- 51. "Nonlinear Waveguides," 1987 International Topical Meeting on Optical Bistability, Instability and Optical Computing, Beijing, 1987.
- 52. "Nonlinear Phenomena in Guided Wave Optics," 1987 Annual Meeting of the Optical Society of America, Rochester, 1987.

المستعمدة والمتناز والدورون والمتاها والمتاها والمتاها والمتاها والمتاها والمتاها والمتاها والمتاها والمتاها

END DATE FILMED 5-88 DTIC